

Radio recombination line spectroscopy with LOFAR



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LOFAR Status Meeting
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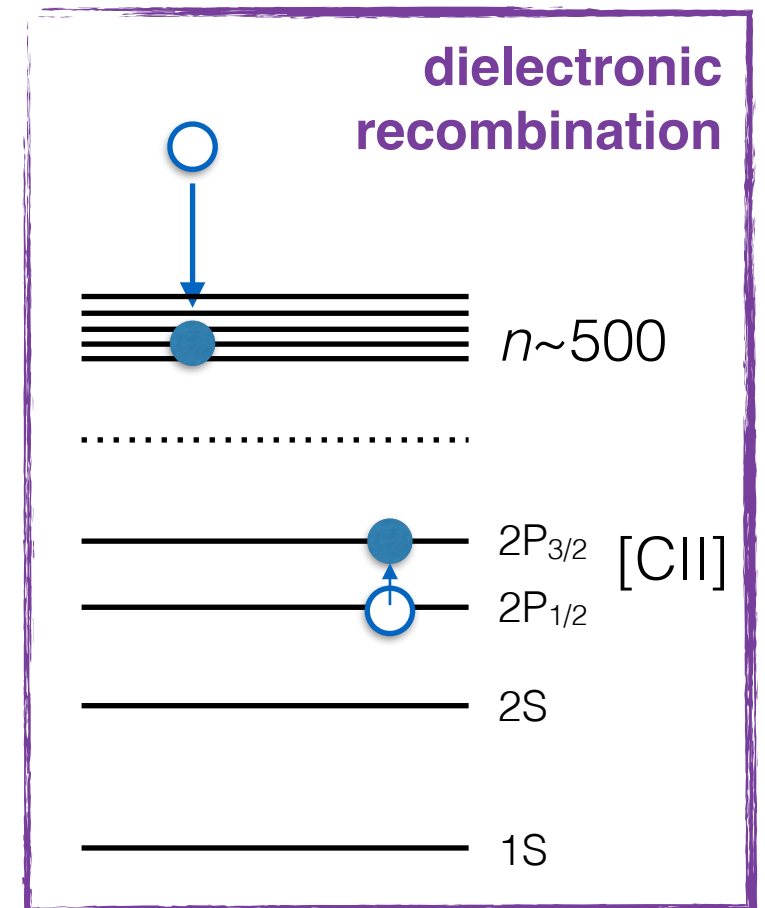
Overview of CRRLs

1. cold ($T \sim 10\text{--}100\text{ K}$), diffuse ($n_e \sim 0.01\text{--}1\text{ cm}^{-3}$)
radiation field $E \sim 11.3\text{--}13.6\text{ eV}$

2. **dielectronic recombination**
electrons at high n (e.g. $n \sim 500$)

3. **low frequencies** ($< 1\text{ GHz}$)

Carbon $\alpha(\Delta n = 1), \beta$ transitions against bright continuum



UPDATED models of physical conditions (*Salgado+ submitted 2015a,b*)

- + radiative transfer, **atomic data** and **full n,l method**
- + with **better computing power**

AGN candidates

- $S(178 \text{ MHz}) > 5 \text{ Jy}$
 - compact, steep-spectrum
 - cold gas detection: HI (absorption), CO, H₂, etc.
-
- LOFAR Tier 1 survey of Northern Sky
 - 8hrs/pointing, HBA
 - peak optical depths $< 10^{-3}$ Hz (10 lines)
 - ~200 objects

3C 48

calibrator

$S(150\text{MHz}) \sim 65 \text{ Jy}$

$z = 0.367$

high far IR dust peak

CO detected (Scoville+ 1993)

$I(\text{CO}(0-1)) = 2.4 \text{ K km/s}$

HBA:

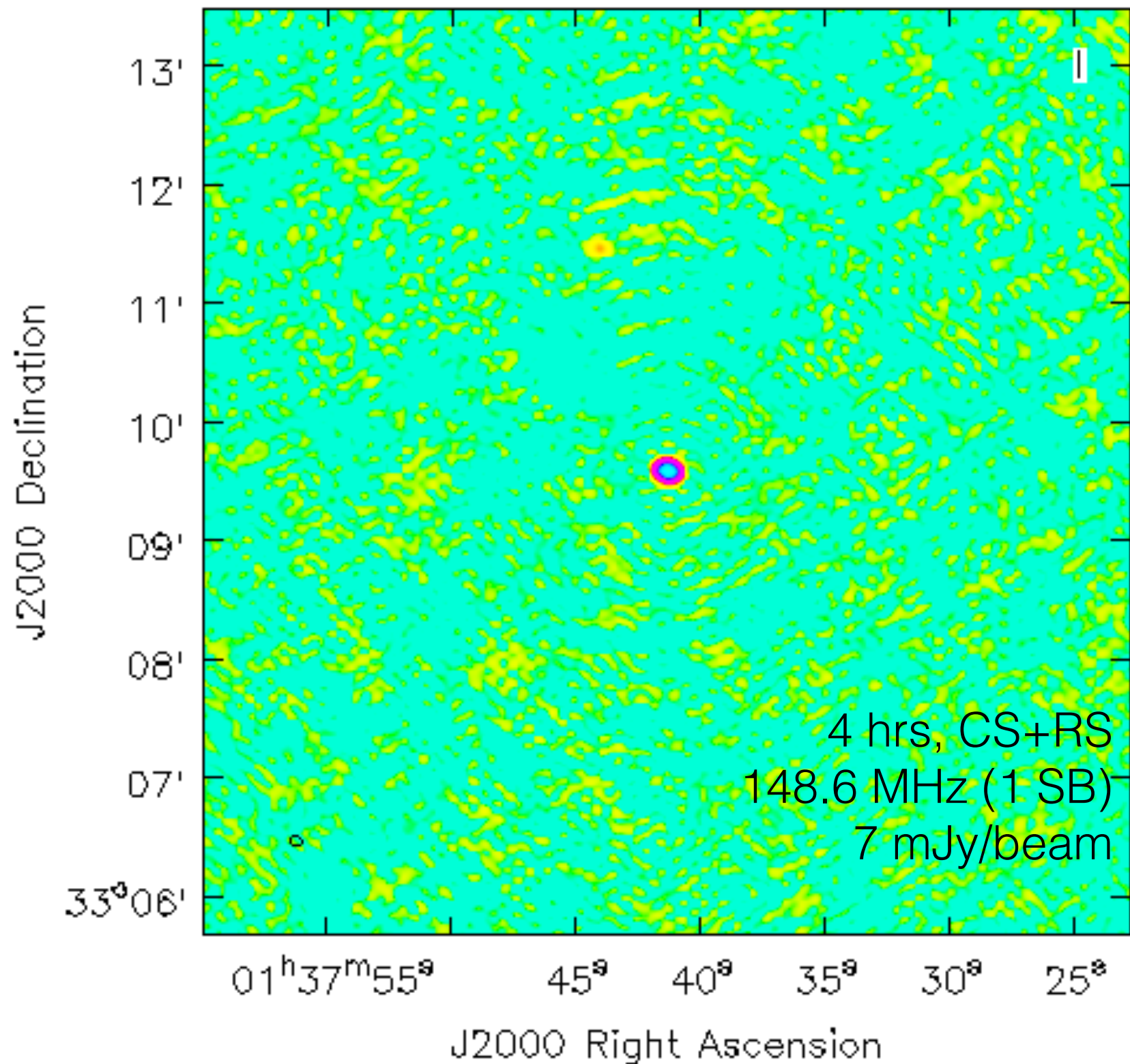
10hr, 110-190 MHz

$\sim 50 \text{ C}\alpha$ lines

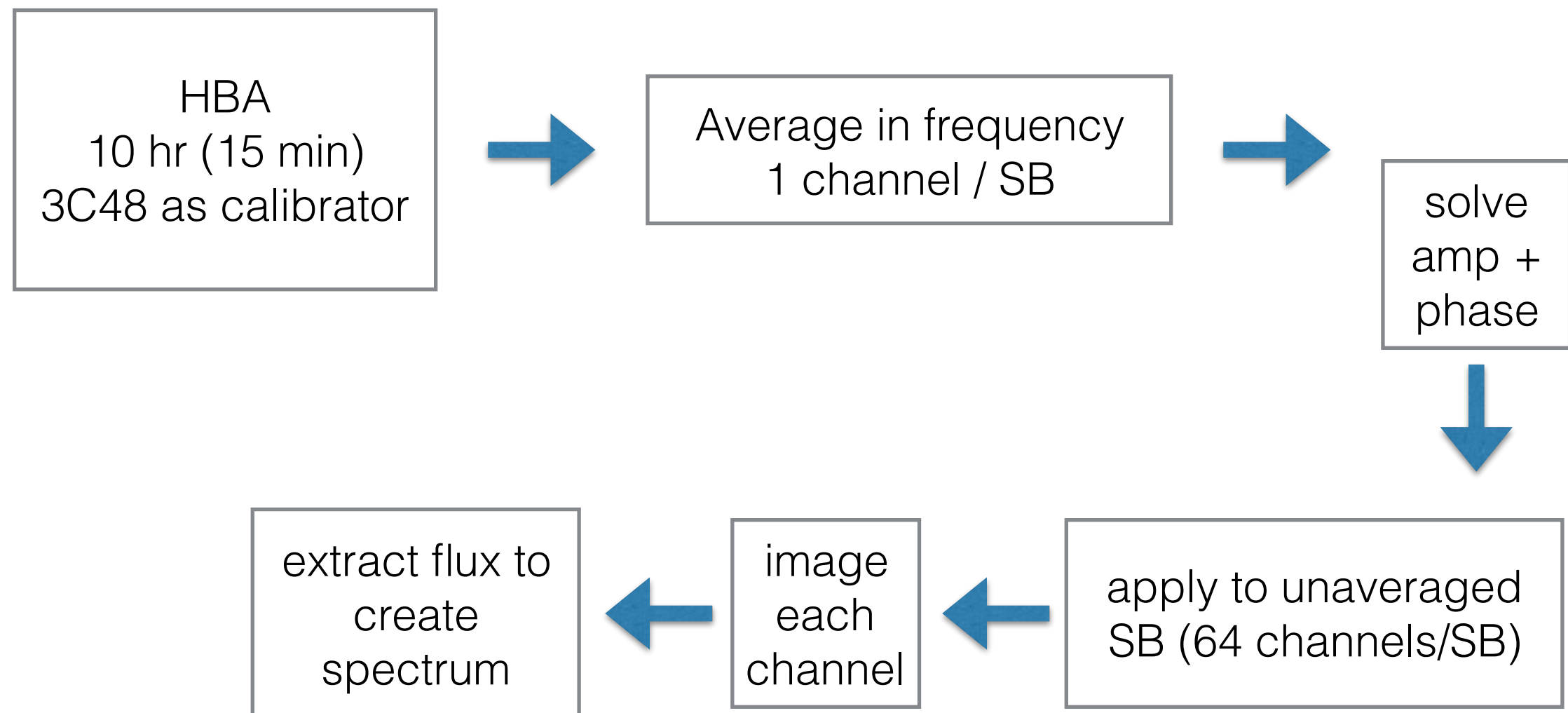
LBA:

6 hr, 30-78 MHz

$\sim 300 \text{ C}\alpha$ lines



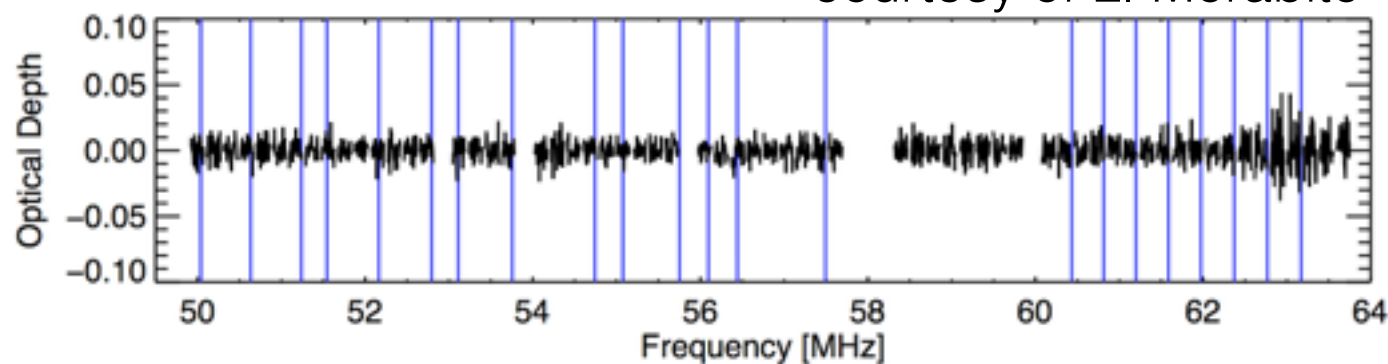
RRL Reduction Procedure



Understanding our spectra

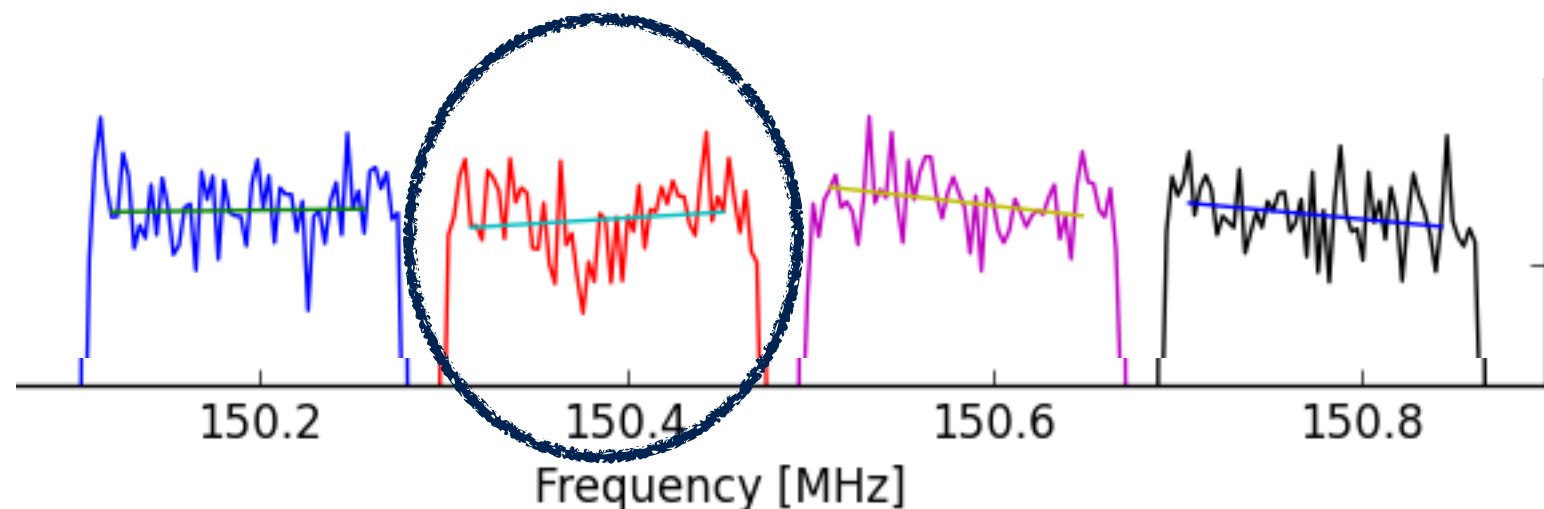
M82 LBA spectrum

courtesy of L. Morabito

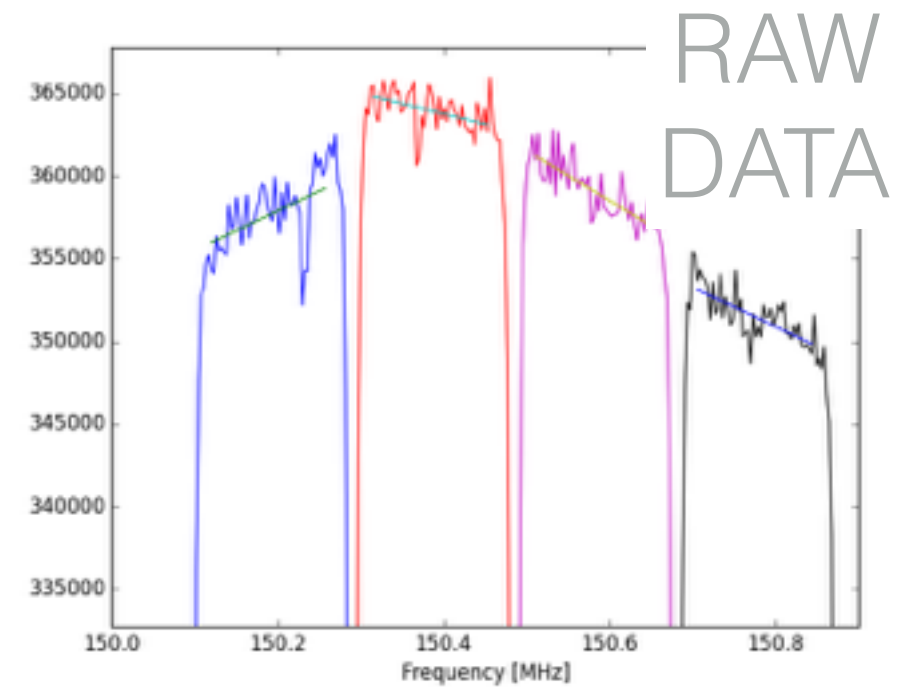
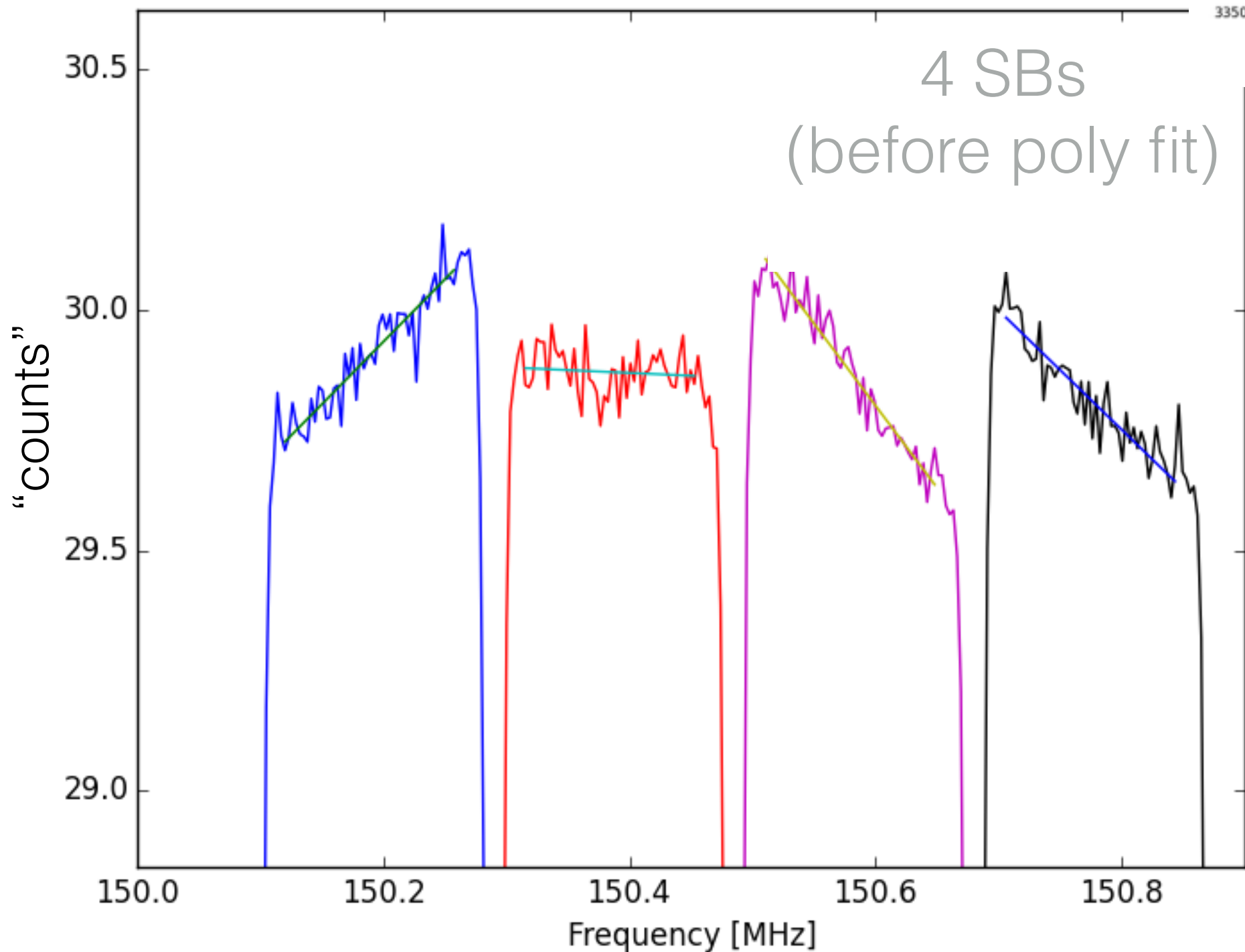


- subbands fitted with 1 or 2 D polynomials

- evidence of larger scale features?

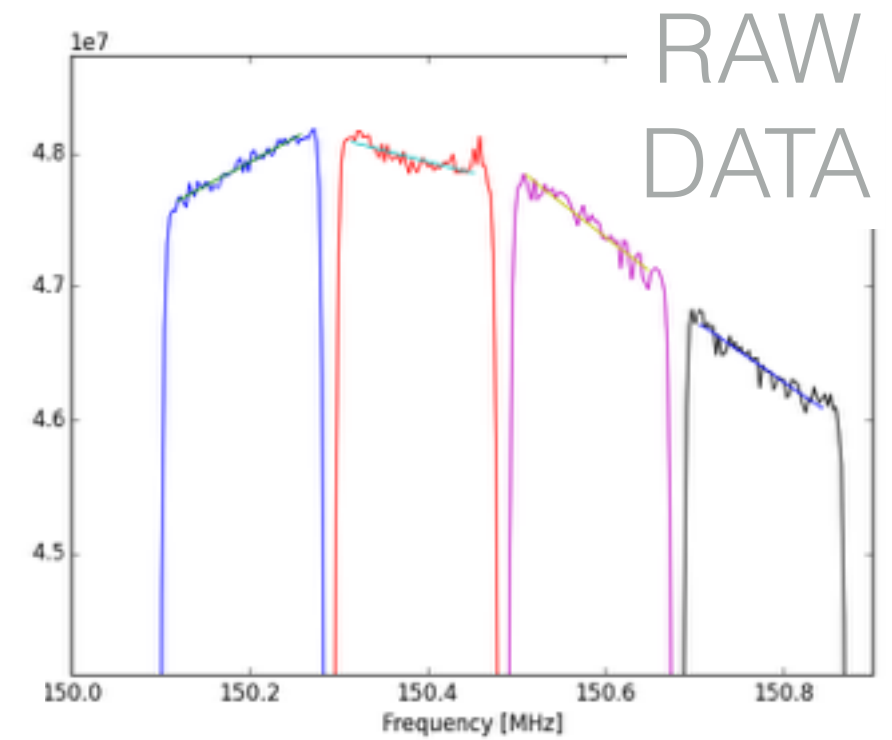
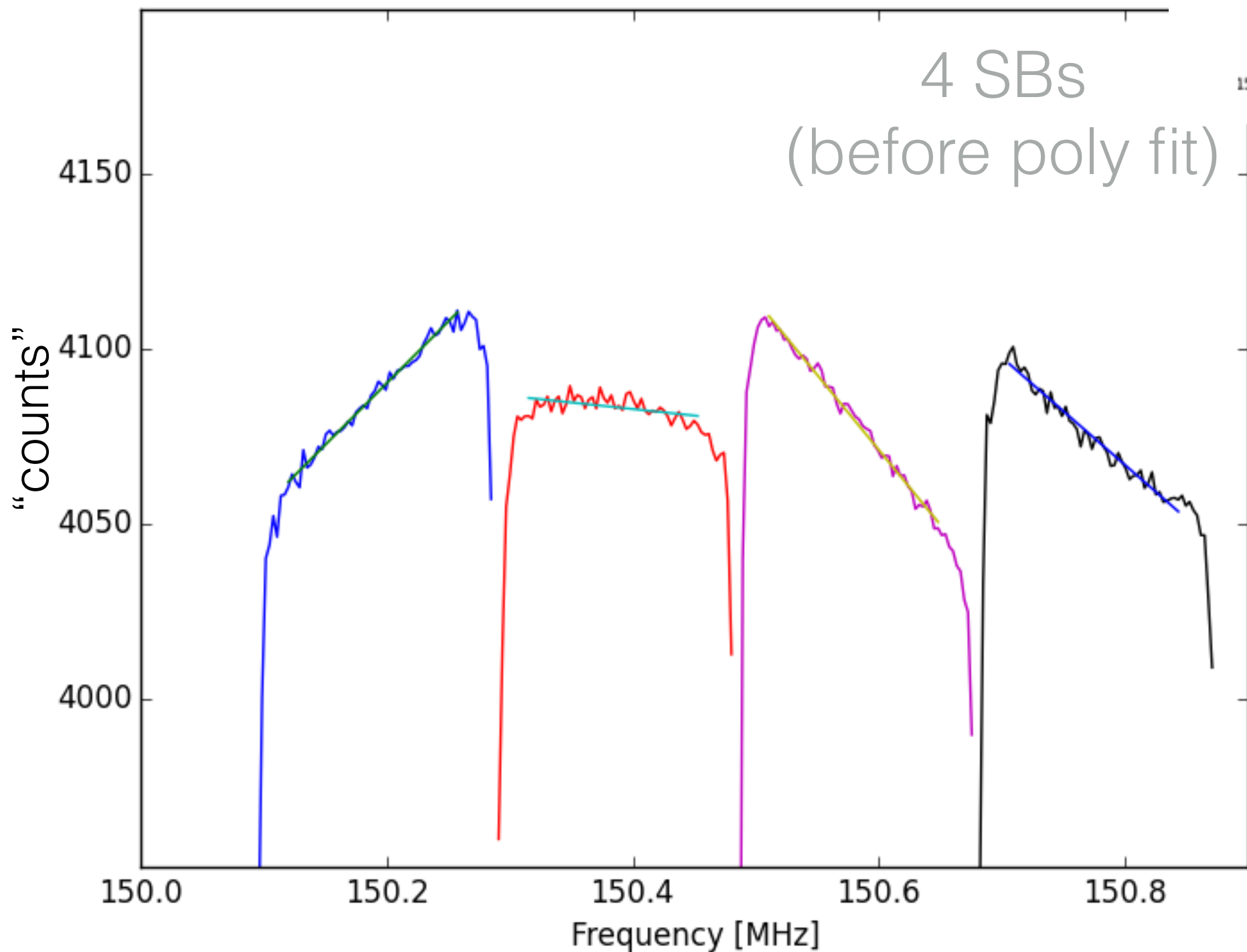


3C 48: sub-bandpass response

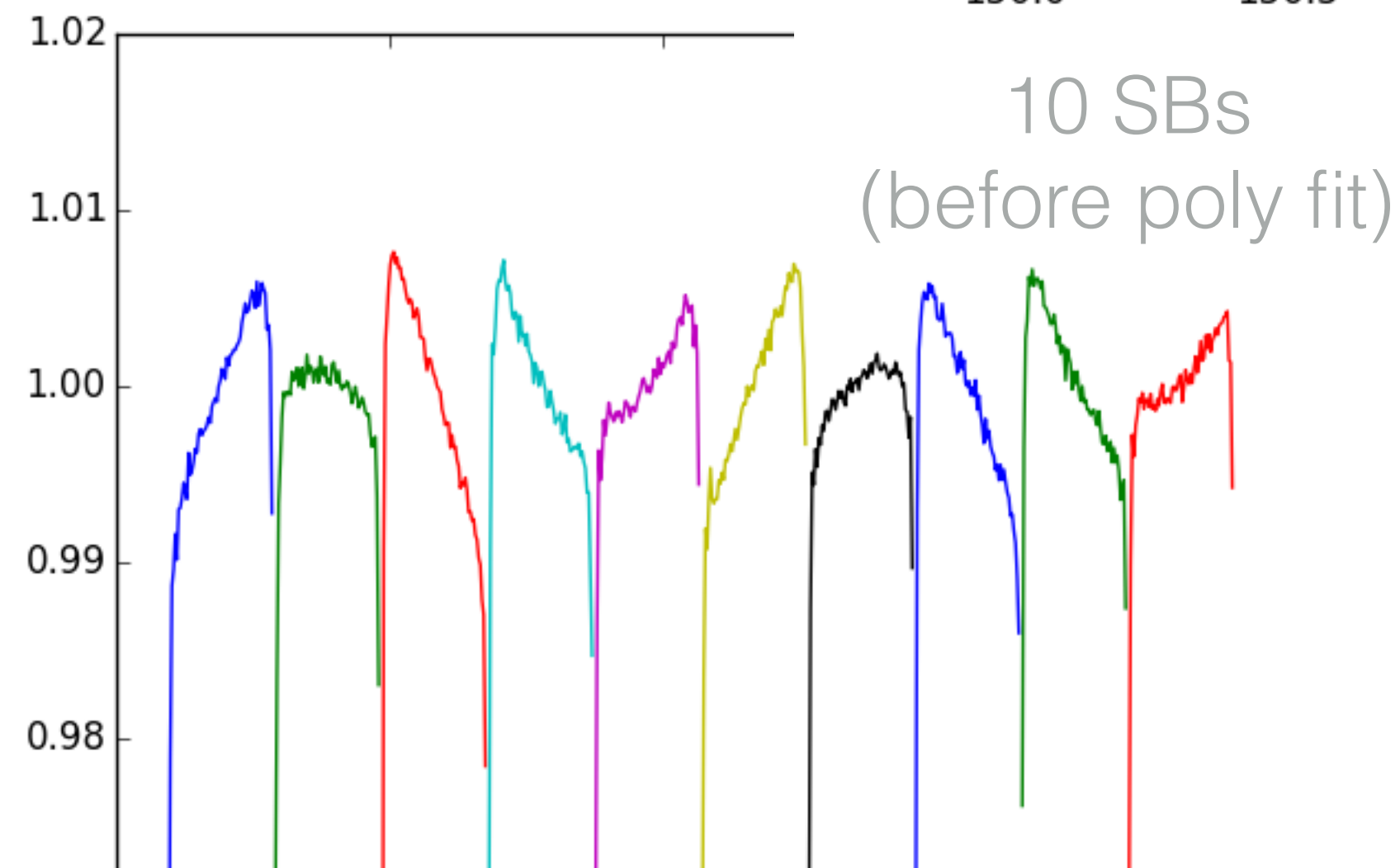
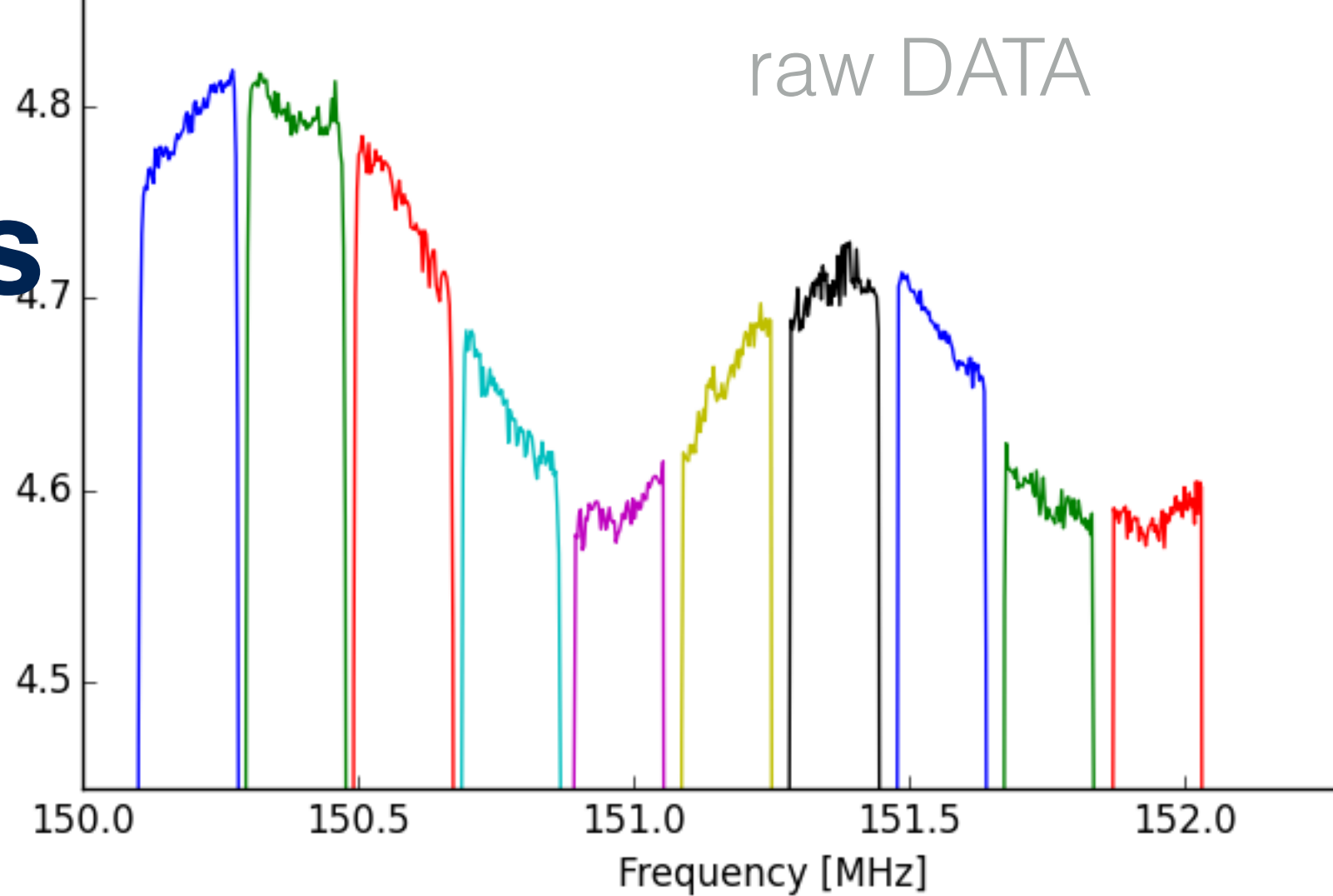


Cyg A

- 15 min obs,
taken 1 hr apart
- same processing



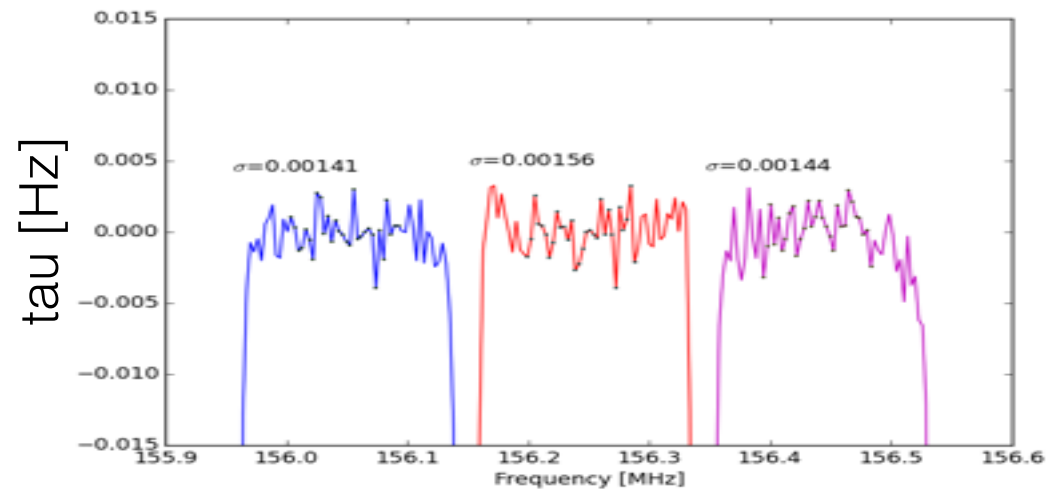
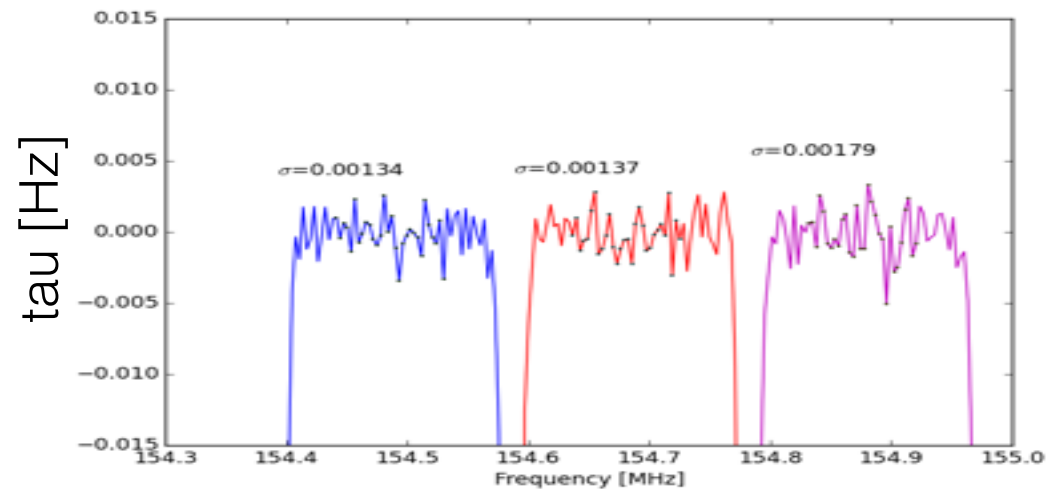
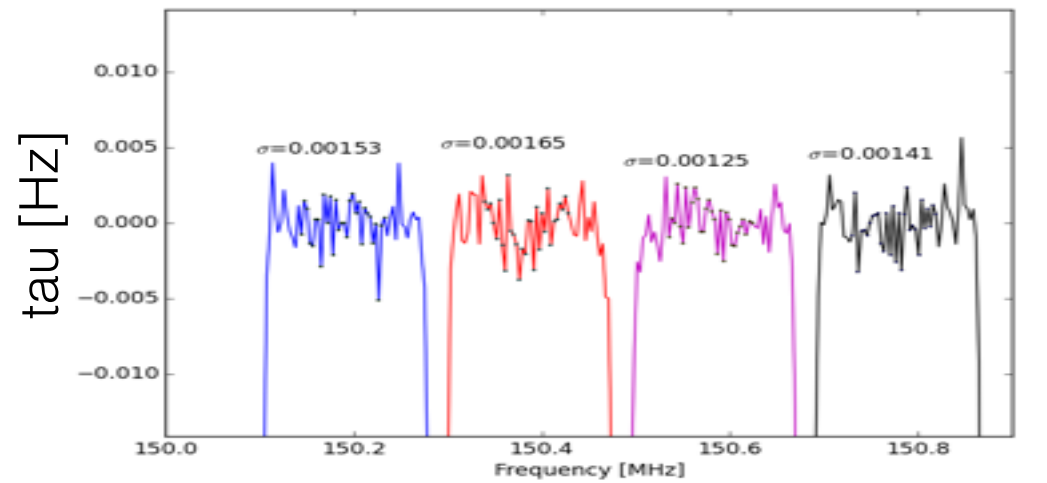
Sub-Bandpass Response



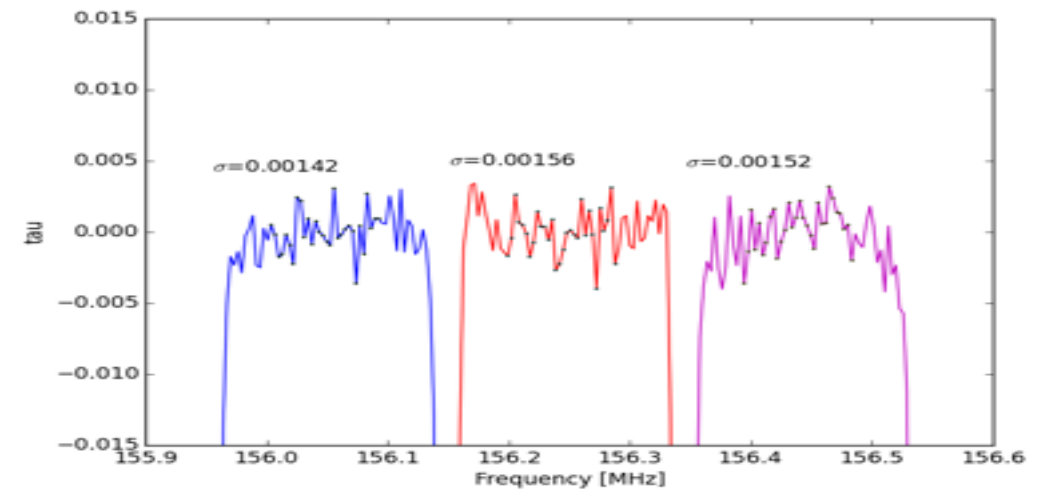
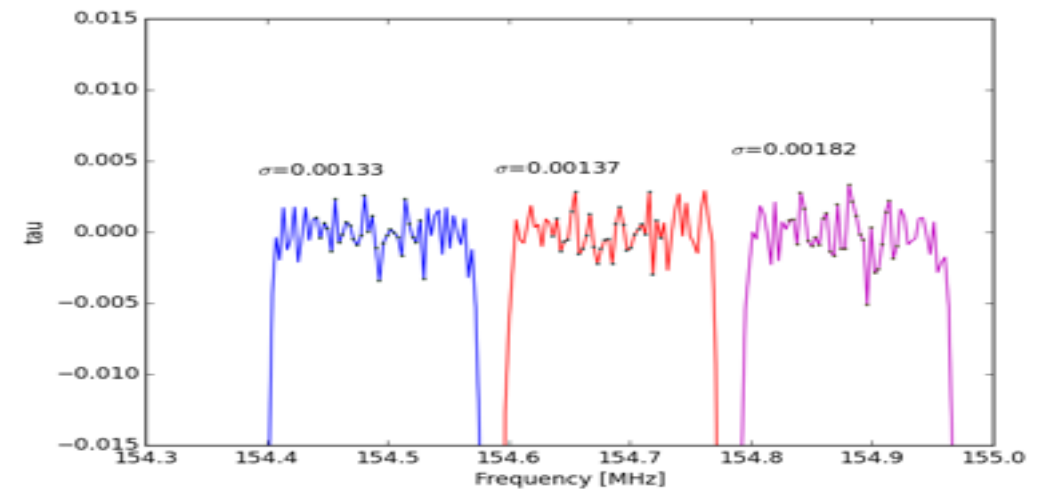
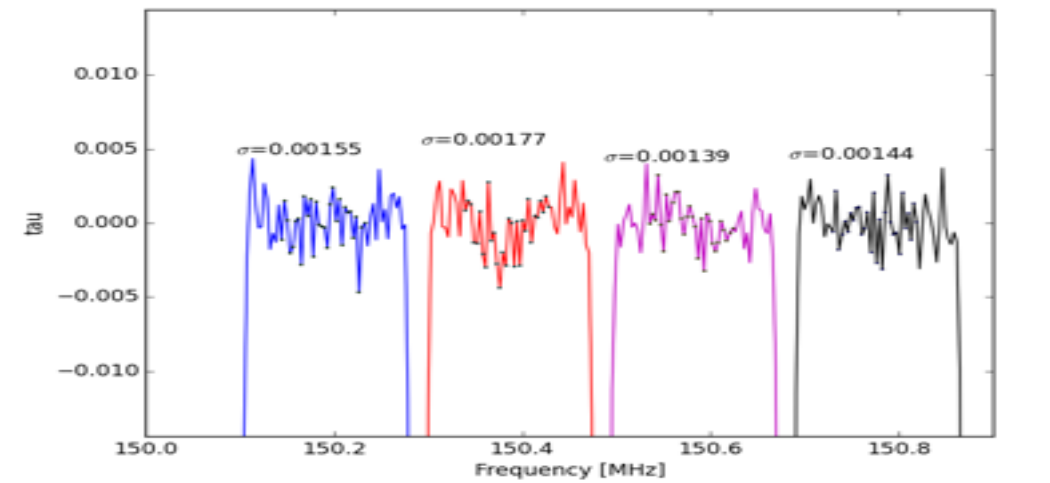
intrinsic shape
remains +
flux rescaled

3C 48 Spectra

Fit 1D poly

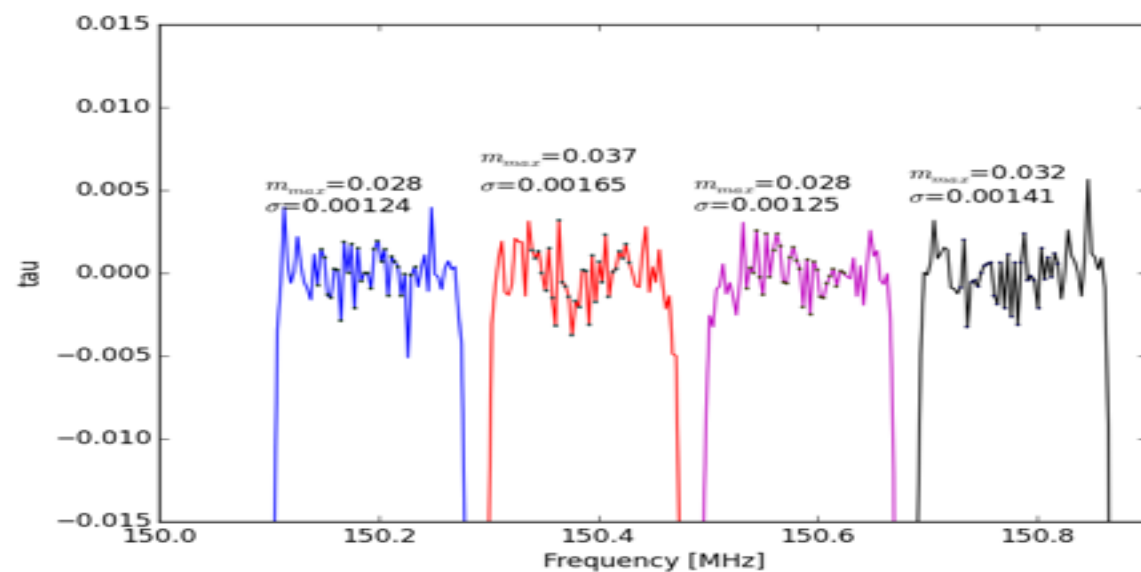


Fit 1D poly to **Cyg A**



Cyg A as bandpass calibrator: observed **same night**

Fit 1D poly



sigma

m_max

= $2 \times \text{rms} / \Delta \nu$

1.24×10^{-3}

0.028

1.65×10^{-3}

0.037

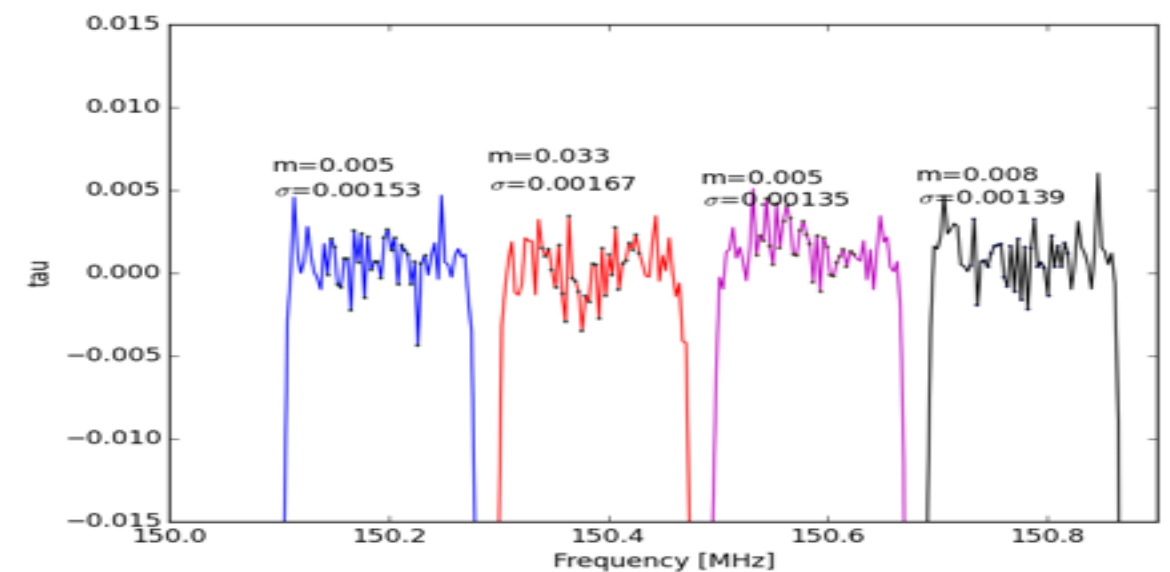
1.25×10^{-3}

0.028

1.41×10^{-3}

0.032

Fit 1D poly to **Cyg A**



sigma

slope

1.53×10^{-3}

0.005

1.67×10^{-3}

0.033

1.35×10^{-3}

0.005

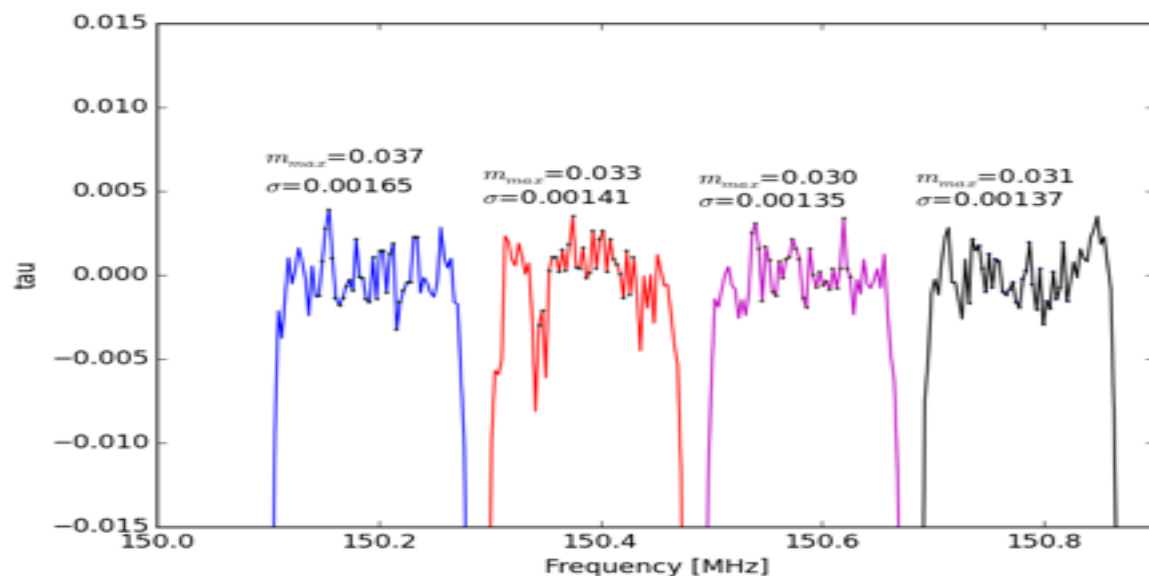
1.39×10^{-3}

0.008

Cyg A as bandpass calibrator: observed 2 years apart

Fit 1D poly

Oct 2013
30min (of 10 hr obs)



sigma

m_max

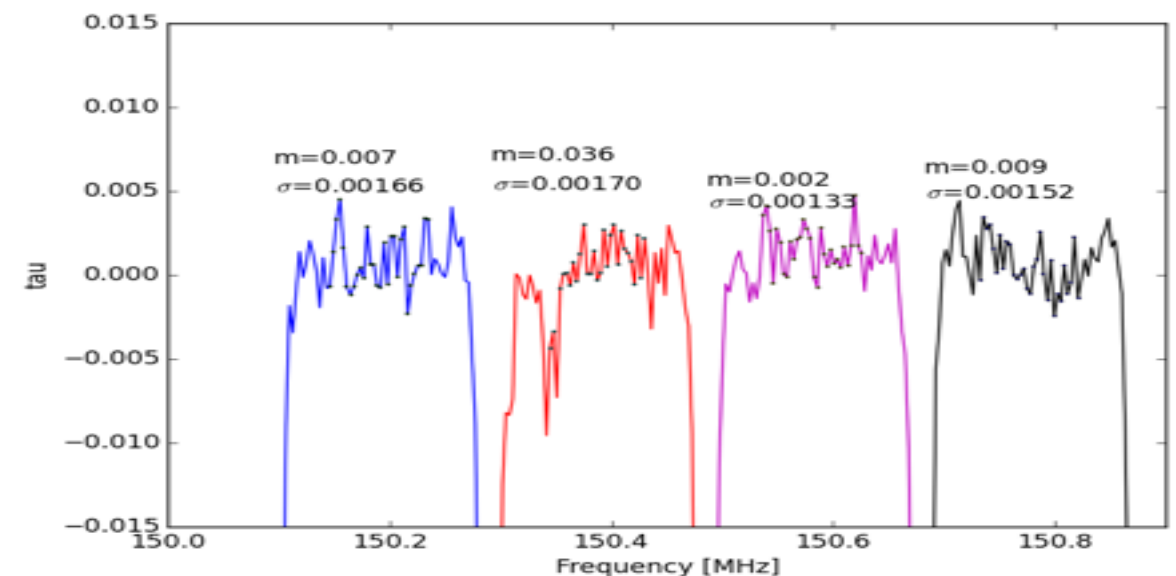
= 2*rms / delta nu

1.65×10^{-3}
 1.41×10^{-3}
 1.35×10^{-3}
 1.37×10^{-3}

0.037
 0.033
 0.030
 0.031

Fit 1D poly to **Cyg A**

Nov 2015
15 min



sigma

slope

1.66×10^{-3}
 1.70×10^{-3}
 1.33×10^{-3}
 1.52×10^{-3}

0.007
 0.036
 0.002
 0.009

Conclusions

- RRLs searches in AGN have started
- 3C48 (15 min) rms $\sim 1.5 \times 10^{-3}$ Hz
- 3C48 (4 hr) rms $\sim 6 \times 10^{-4}$ Hz
- (sub-) bandpass calibration
 - same night observations (?)
 - applicable over longer timescales (?)